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PTO/SB/05 (12/97)
Approved for use through 09/30/00. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No. 002240.P015D   Total Pages 5

First Named Inventor or Application Identifier Gary S. Chisholm

Express Mail Label No. EL034143096US

ADDRESS TO: **Assistant Commissioner for Patents**
Box Patent Application
Washington, D. C. 20231

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. X Fee Transmittal Form
(Submit an original, and a duplicate for fee processing)

2. X Specification (Total Pages 21)
(preferred arrangement set forth below)
- Descriptive Title of the Invention
- Cross References to Related Applications
- Statement Regarding Fed sponsored R & D
- Reference to Microfiche Appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings (if filed)
- Detailed Description
- Claims
- Abstract of the Disclosure

3. X Drawings(s) (35 USC 113) (Total Sheets 6)

4. X Oath or Declaration (Total Pages 4)
   a. ___ Newly Executed (Original or Copy)
   b. X Copy from a Prior Application (37 CFR 1.63(d))
   (for Continuation/Divisional with Box 17 completed) **(Note Box 5 below)**
   i. ___ DELETIONS OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).

5. X Incorporation By Reference (useable if Box 4b is checked)
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

6. ___ Microfiche Computer Program (Appendix)

7. __ Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
   a. ___ Computer Readable Copy
   b. ___ Paper Copy (identical to computer copy)
   c. ___ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

8. ____ Assignment Papers (cover sheet & documents(s))
9. ____ a. 37 CFR 3.73(b) Statement (where there is an assignee)
   ____ b. Power of Attorney
10. ____ English Translation Document (if applicable)
11. ____ a. Information Disclosure Statement (IDS)/PTO-1449
    ____ b. Copies of IDS Citations
12. X Preliminary Amendment
13. X Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
14. ____ a. Small Entity Statement(s)
    ____ b. Statement filed in prior application, Status still proper and desired
15. ____ Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. X Other: Copy of postcard w/certificate of Express Mail.

17. **If a CONTINUING APPLICATION,** check appropriate box and supply the requisite information:

____ Continuation X Divisional ____ Continuation-in-part (CIP)

of prior application No: 08/676,719

18. **Correspondence Address**

____ Customer Number or Bar Code Label ____________________
(Insert Customer No. or Attach Bar Code Label here)

or

X Correspondence Address Below

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FEE TRANSMITTAL

TOTAL AMOUNT OF PAYMENT ($) 790.00

Complete if Known:
Application No. Not Yet Assigned
Filing Date Herewith
First Named Inventor Gary S. Chisholm
Group Art Unit Not Yet Assigned
Examiner Name Not Yet Assigned
Attorney Docket No. 002240.P015D

METHOD OF PAYMENT (check one)

1. [X] The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

Deposit Account Number 02-2666
Deposit Account Name ______

[X] Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17

[ ] Charge the Issue Fee Set in 37 CFR 1.18 at the Mailing of the Notice of Allowance, 37 CFR 1.131(b)

2. X Payment Enclosed
X Check
___ Money Order
___ Other

FEE CALCULATION (fees effective 10/01/97)

1. FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	790	201	395	Utility application filing fee	$790
106	330	206	165	Design application filing fee	
107	540	207	270	Plant filing fee	
108	790	208	395	Reissue filing fee	
114	150	214	75	Provisional application filing fee	

SUBTOTAL (1) $ 790.00

2. CLAIMS

			Extra		Fee from below		Fee Paid
Total Claims	10	− 20 =	0	X	$22	=	$0.00
Independent Claims	1	− 3 =	0	X	$82	=	$0.00
Multiple Dependent Claims			_	X	___	=	___

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
103	22	203	11	Claims in excess of twenty	$0.00
102	82	202	41	Independent claims in excess of 3	$0.00
104	270	204	135	Multiple dependent claim	
109	82	209	41	Reissue independent claims over original patent	
110	22	210	11	Reissue claims in excess of 20 and over original patent	

SUBTOTAL (2) $ 0.00

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for response within first month	
116	400	216	200	Extension for response within second month	
117	950	217	475	Extension for response within third month	
118	1,510	218	755	Extension for response within fourth month	
128	2,060	228	1,030	Extension for response within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive unavoidably abandoned application	
141	1,320	241	660	Petition to revive unintentionally abandoned application	
142	1,320	242	660	Utility issue fee (or reissue)	
143	450	243	225	Design issue fee	
144	670	244	335	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	790	246	395	For filing a submission after final rejection (see 37 CFR 1.129(a))	
149	790	249	395	For each additional invention to be examined (see 37 CFR 1.129(a))	

Other fee (specify) ____________________ ________

Other fee (specify) ____________________ ________

SUBTOTAL (3) $ 0.00

*Reduced by Basic Filing Fee Paid

SUBMITTED BY:

Typed or Printed Name: Tarek N. Fahmi

Signature ____________ Date March 26, 1998

Reg. Number 41,402 Deposit Account User ID ____________
(complete if applicable)

PTO/SB/17 (10-96)
Approved for use through 09/30/98 OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Attorney's Docket No.: 02240.P015D <u>Patent</u>

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Patent Application of:	
Gary S. Chisholm et al.	Examiner: Not Yet Assigned
Application No: Not Yet Assigned	Art Unit: Not Yet Assigned
Filed: Herewith	
For: METHOD AND APPARATUS FOR PRECISE POSITIONING OF LARGE STRUCTURES	
A Divisional of:	
Application No.: 08/676,719	Prior Examiner: Mojica, V.
Filed: July 8, 1996	Prior Art Unit: 3613

Assistant Commissioner for Patents
Washington, D.C. 20231

<u>PRELIMINARY AMENDMENT</u>

Sir:

Prior to the examination of this application on the merits it is respectfully requested that the following amendments be entered.

<u>IN THE CLAIMS</u>

Please cancel claims 1-10 and 21.

"Express Mail" mailing label number: EL034143096US
Date of Deposit: March 26, 1998
I hereby certify that I am causing this paper or fee to be deposited with the United States Postal Service "Express Mail Post Office to Addressee" service on the date indicated above and that this paper or fee has been addressed to the Assistant Commissioner for Patents, Washington, D. C. 20231
Patricia A. Balero
(Typed or printed name of person mailing paper or fee)
[signature]
(Signature of person mailing paper or fee)
3/26/98
(Date signed)

REMARKS

This is a divisional application filed under Rule 53(b). In response to a restriction requirement set forth in the Office Action of March 5, 1998, in the parent application, claims 1-10 and 21, corresponding to groups 1 and 3, have been canceled. Accordingly, claims 11-19 are presented for examination on the merits.

If there are any deficiencies of fees associated with this communication, please charge our Deposit Account No. 02-2666.

Respectfully submitted,

BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN LLP

Dated: 3/26, 1998

Tarek N. Fahmi
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UNITED STATES PATENT APPLICATION

for

METHOD AND APPARATUS FOR PRECISE POSITIONING OF LARGE STRUCTURES

Inventors:

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File No.: 002240.P015

EXPRESS MAIL MAILING CERTIFICATE

I hereby certify that this correspondence is being deposited with the United States Postal Service as Express Mail No. EM531599129US *in an envelope addressed to: The Commissioner of Patents and Trademarks, Washington, D.C. 20231 on:* 7-8-96

Cristina M Kennard 7-8-96

Name: CRISTINA M. KENNARD *(Date)*

Method and Apparatus for Precise Positioning of Large Structures

FIELD OF THE INVENTION

The present invention relates generally to real time navigation systems and, more particularly, to the use of such systems for the precise positioning of large structures.

BACKGROUND

In the marine environment, construction personal are often faced with task of positioning large, three dimensional structures within confined spaces. For example, during construction in ports and other areas, it is common for structures such as bridge sections and tunnel sections to be moved by crane and barge into a desired location. Also, during the construction of oil-rig platforms, it is common for large pilings to be placed on the ocean floor using a piling-rig.

Accurate, on going determination of the position of structures such bridge sections is required during all phases of the construction operation. In order that the bridge be properly configured at completion, horizontal and vertical displacements of even a few centimeters must be avoided. Displacements which are accidentally built into the path of a bridge, for example, may require expensive correction before the bridge can be placed in operation.

Traditional methods of monitoring the placement of structures such as a bridge under construction involve the use of a variety of surveying techniques. These may include visible lasers and/or optical theodolites. Such methods are not particularly convent because they require trained personal to visit the construction site each time a new bridge section is being placed.

Modern surveying methods are able to make use of remote positioning systems which may be satellite- or land-based. The satellite system most commonly used today is the Global Positioning System (GPS) although others, such as the Global Orbiting Navigation System (GOLNASS) are also in use or under development. Some land-base systems which effectively simulate the satellite-based systems for a small area are also in development. These generally involve the use of pseudolites. Engineering and surveying methods which use these systems can be markedly more efficient and accurate than traditional methods.

Use of GPS in surveying typically involves a single operator who sets up a base station with an antenna positioned over a control point having a known position. The surveyor then moves about a construction site with a mobile unit having its own antenna. The operator places the mobile antenna over unknown survey points in the field to record their position using signals transmitted by a number of in-view satellites. A vector or baseline is determined from the basesite to the mobile unit. Survey points whose positions are measured in this fashion may, in turn, become control points from which measurements of other unknown points may be taken. The use of GPS during a survey procedure may be combined with other techniques such as distance and angle measurements taken with GPS stations which may be placed at one of the control points.

Each GPS satellite transmits two coded L-band carrier signals which enable some compensation for propagation delays though the ionosphere. Each GPS receiver contains an almanac of data describing the satellite orbits and uses ephemeris corrections transmitted by the satellites themselves. Satellite to antenna distances may be deduced from time code or carrier phase differences determined by comparing the received signals with locally generated receiver signals. These distances are then used to determine the antenna position. Only those satellites which are sufficiently above the horizon can contribute to a position measurement, the accuracy of which depends on various factors including the geometrical arrangement of the satellites at the time when the distances are determined.

Distances measured from an antenna to four or more satellites enable the antenna position to be calculated with reference to the global ellipsoid WGS-84. Local northing, easting and elevation coordinates can then be determined by applying appropriate datum transformation and map projection. By using carrier phase differences in any one of several known base or mobile receiver techniques, the mobile antenna coordinates can be determined to an accuracy on the order of $\pm$ 1cm. Using such real time kinematic (RTK) techniques, an operator can obtain position measurements within seconds of placing a mobile antenna on a unknown point. In RTK systems, satellite correction data is transmitted by a radio or other link between the base and mobile receivers, whether or not there is a clear line of site to ensure that accuracy in the mobile position measurements is maintained and the survey information is correct.

SUMMARY OF THE INVENTION

According to one embodiment, a three dimensional structure is precisely positioned at a desired location. To begin, a virtual model of the structure of interest is created and stored in a computer memory. Some time later, remote sensors are placed in selected positions on the actual structure of interest. The sensors are configured so as to provide real time location, attitude and orientation information regarding the structure and may consist of GPS remote units, tilt meters, gyro compasses, and pressure sensors. The position of each remote sensor on the actual structure is also recorded in the computer memory so that the virtual model of the structure accurately reflects the real world situation. As the structure is being positioned, real time location, attitude and orientation information produced by the remote sensors is monitored at a base station and used to update the virtual model with respect to a predefined coordinate system. In this way, the virtual model accurately reflects the current location, attitude and orientation of the structure. The information so obtained can be displayed to a user as a graphical and textual representation of the current state of the structure. In addition,

the desired location, attitude and orientation of the structure is displayed. Such a display is then used by an operator to adjust the current location, attitude and orientation of the structure so as to align the current position of the structure with the desired position. In this way, this structure can be precisely positioned. As built reports can be generated once the positioning operation is complete.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures in the accompanying drawings in which:

Figure 1 is a schematic view illustrating the use of a crane to position a bridge section;

Figure 2 illustrates a precise positioning system according to one embodiment;

Figure 3a illustrates a tilt meter;

Figure 3b illustrates a pair of X-Y tilt vials within the tilt meter of Figure 3a;

Figures 4a-4d illustrate various views of a three dimensional structure; and

Figure 5 is a flow diagram illustrating a method of precisely positioning a large structure according to one embodiment.

DETAILED DESCRIPTION

Referring to the drawings in detail, wherein like numerals designate like parts and components, the following description sets forth numerous specific details in order to provide a though understanding of the present invention. However, after reviewing this specification, it will be apparent to those skilled in the art that the present invention may be practiced without some or all of these specific details. In other instances, well known structures, programming techniques and devices have not been described in detail in order not to unnecessarily obscure the present invention.

Figure 1 illustrates the precise positioning of a bridge section or other large structure according to the present invention. Crane 10 is situated on barge 12 and is in the processes of positioning bridge section 14. Barge 12 may be in the process of navigating a waterway 16 such as a channel or port. As will be described below, the positioning of bridge section 14 is aided by the use of a variety of positioning sensors which are monitored at a base station. The base station may be located on barge 12 within crane 10. Alternatively, the base station may be located at another site.

Figure 2 further illustrates a positioning system according to the present invention. Structure 100 may, in one embodiment, be bridge section 14 as shown in **Figure 1**. Structure 100 may also be any one of a number of other structures, for example, a tunnel section. Located on structure 100 are a verity of sensors including a number of GPS sensors 102, a gyro compass 108, a number of pressure sensors 110, and one or more tilt meters 112. The various sensors 102, 108, 110. and 112 are all linked to a radio 106 via a system bus 104. Radio 106 includes antenna 114 for use in communicating with the a base station 200.

Base station 200 includes a central processing unit 202, a GPS base station 204, memory 208, radio 210, and a display 212. Radio 210 includes antenna 214. Each of these

components is linked by a bus 206. Associated with central processing unit 202 is a keyboard 216 and a mouse or other cursor control device 218. The base station 200 communicates with the various sensors on structure 100 via radio link 220. Those skilled in the art will appreciate that other forms of communication links, such as infra red or other optical links, could be used. Alternatively, conditions permitting, hardwire links could also be used.

Onboard structure 100, each of the various sensors 102, 108, 110, and 112, is positioned in a strategic location. For example, each GPS sensor 102 has a associated antenna 116. Each antenna is positioned in a location of interest onboard structure 100. With reference to bridge section 14 in **Figure 1**, antennas 116 might be positioned at each of the four corners of bridge structure 14 and another antenna 116 might be located on the highest point on bridge structure 14. In this way, positioning information from each location of interest on structure 100 can be obtained from the various GPS sensors 102. Although described with reference to individual GPS sensors 102 for each antenna 116, those skilled in the art will appreciate that a single GPS sensor 102 could be used with a number of antennas 116 connected thereto. In such an embodiment, GPS sensor 102 would include an antenna switch for switching between each of the various antennas 116 located at different positions on structure 100. In this way, positioning information for each location associated with an antenna 116 could be obtained in a sequential fashion. For those applications where simultaneous, real-time positioning information from each location associated with an antenna 116 is not required such an embodiment is sufficient. However, where real-time, simultaneous positioning information is required, individual GPS sensors 102, each with its own antenna 116, will be required.

GPS sensors 102 are each capable of receiving GPS signals from in-view satellites and producing positioning information therefrom. In order to derive centimeter level accurate positioning information, GPS sensors 102 communicate with GPS base station 204 via radio

link 220. GPS base station 204 provides real-time kinematic correction information to allow GPS sensors 102 to produce real-time, centimeter level accurate positioning information. The manner in which such calculations are derived is well known in the art. Alternatively, GPS base station 204 could produce differential GPS (DGPS) correction information and provide same to GPS sensors 102 via radio link 220. Those skilled in the art will appreciate that if DGPS correction data is used, the positioning information derived from GPS sensors 102 will be on the order of $\pm$ 1 meter.

In addition to GPS sensors 102, structure 100 includes other sensors. For example, gyro compass 108 is located on structure 100 and produces orientation information regarding structure 100 with reference to true north. If gyro compass 100 is properly aligned with a centerline or other reference on structure 100, real-time heading information regarding structure 100 can be obtain from gyro compass 108. Those skilled in the art will appreciate that the use of a gyro compass 108 involves certain limitations. For example, gyro compass 108 requires a certain setup time, on the average of four hours, before accurate heading information is available. In some cases, gyro compass 108 may be a ring laser gyro compass, however, this will still require a sufficient setup time. In alternative embodiments, the use of gyro compass 108 is not required because GPS sensors 102 with associated antennas 116 are located along the centerline or other reference line of structure 100. By comparing the relative positions of each of the antennas 116 so located, a vector between the antennas can be derived and the orientation of structure 100 with respect to a given coordinate system can be derived therefrom.

For the case where portions of structure 100 will be located below water level, pressure sensors 110 are mounted in various locations. The use of pressure sensors 110 allows for the transmission of pressure or depth information via radio link 220. Such information can be used for the accurate positioning of structure 100.

In addition, various tilt meters 112 can also be located on structure 100 in strategic locations. Tilt meters 112 can provide accurate two dimensional orientation data concerning structure 100. Referring briefly to **Figures 3a** and **3b**, an exemplary tilt meter 112 is shown. Tilt meter 112 includes a plate 302 for attachment to structure 100 and housing 300 which is fastened to the plate 302 by a bracket 304. Lid 308 of the housing 300 can be removed to reveal two perpendicular vials 310 which lie parallel to the bracket 304. Liquid in each vial 310 is electrically monitored by circuitry within the housing 300 to produce tilt measurement data though output ports 306. Each tilt meter 112 is mounted on structure 100 in a known orientation, preferably to yield tilt data in a horizontal or vertical plane. Each tilt meter 112 is then calibrated in this known state of tilt. The vials 310 are preferably oriented to yield Cartesian tilt components. Where required, the Cartesian tilt components may be converted later into angler bearing and deviation components. Placement and calibration of tilt meters 112 will normally take place under controlled conditions when the structure 100 is laying horizontal and not subject to movement. The vials 310 are adjusted and locked by screws 312 during the calibration process. For the example shown in **Figure 1**, tilt meters 112 may be positioned along horizontal and vertical members of bridge section 14. Tilt meters 112 so positioned would give orientation data in the horizontal and vertical planes, thus allowing accurate positioning of bridge section 14.

Alternatively, tilt meters 112 may be calibrated using software. In such an embodiment, tilt meters 112 are attached to structure 100 in strategic locations, e.g., along the major axes of structure 100, while structure 100 is stationary. Tilt measurement data obtained from output ports 306 is interfaced to CPU 202, e.g. using a communication link as discussed below, or a serial or other data connection. Software running on CPU 202 interprets the tilt measurement data and generates a tilt value for each axis. The tilt value is then stored to be used later as a correction factor (or calibration value) for all subsequent tilt measurements. For example, if the initial tilt value was determined to be 2.123^{c} of roll, all

subsequent tilt measurements would first be corrected by subtracting 2.123 ᶜ of roll before a final tilt value was produced. This is similar to taring a scale while weighing a container and its contents.

Returning to **Figure 2**, base station 200 receives the various positioning information, including GPS information from GPS sensors 102, orientation information from gyro compass 108, pressure or depth information from pressure sensors 110, and tilt data from tilt meters 112 via radio link 220. Radio signals from structure 100 are received at antenna 214 and demodulated by radio 210 under the control of central processing unit (CPU) 202. This data may be stored in memory 208 or another data storage device (not shown) for archiving purposes. In other embodiments, CPU 202 is located onboard structure 100 to provide onboard operators with real-time positioning displays as discussed below. In such cases, radio link 220 is primarily used to transmit RTK or DGPS correction information between GPS base station 204 and GPS sensors 102.

CPU 202 is also provided with a virtual model of structure 100. The virtual model is a three dimensional digital representation of the structure 100 and is typically stored in memory 208 prior to the positioning operation. **Figure 4** shows how an arbitrary three dimensional structure might be represented in a virtual model. Structure 400 is defined with reference to an XYZ coordinate system as shown. Structure 400 might represent a bridge section such as bridge section 14 shown in **Figure 1**, or some other structure that requires positioning. Using programming techniques well known in the art, structure 400 is represented in a digital format and stored in a data structure in memory 208. As each of the sensors 102, 108, 110 and 112 are positioned on the real world structure 400, their locations are recorded within the virtual model. For example, GPS antennas 116 might be located at positions 404 and 402. These reference points are included in the virtual model with reference to the XYZ coordinate system. Similarly, pressure sensors 110 might be located at positions 406. Positions 406 are also recorded in the virtual model with the reference to

XYZ coordinate system. In this way, the virtual model is updated to reflect the real world configuration of structure 400.

The XYZ coordinate system is a local coordinate system. This may be translated to a real world coordinate system using transformation techniques well known in the art.

The virtual model so established can be used for accurate positioning of structure 100 as follows and as illustrated in the flow diagram of **Figure 5**. **Figure 5** shows a process 500 for the precise positioning of a structure 100 such as bridge section 14 shown in **Figure 1**. At step 502, the virtual model of the structure of interest is established and stored in memory. As indicated above, the virtual model is a three dimensional digital representation of the structure of interest and is stored as data structure. At step 504, various sensors are positioned on the structure. As discussed above, these include GPS sensors, gyro compasses, pressure sensors and/or tilt meters. At step 506, the virtual model is updated with the sensor location information as described above.

At step 508, structure 100 is in the process of being positioned. During the positioning process, the sensor data provided by the remote sensors is monitored at the base station 200 using radio link 220. In one embodiment, real-time sensor information from each of the sensors positioned on structure 100 is multiplexed on a radio signal by radio 106 and transmitted via antenna 114 across radio link 220 to radio 210 located at base station 200. Radio 210 receives the radio link transmission 220 via antenna 214 and demultiplexes and demodulates the radio signal so as to present each of the individual sensor data on bus 206. For those embodiments where CPU 202 is located onboard structure 100, the sensor data is monitored through the use of hard wired connections between the sensors and CPU 202. For convenience, the remainder of this discussion assumes that radio link 220 is used.

At step 510, CPU 202 uses the real-time sensor data provided by radio 210 to update the virtual model stored in memory 208. The virtual model is updated to represent the actual location, attitude and orientation of structure 100 as it is being positioned. In this regard,

sensor data from GPS sensors 102, aided by correction information from GPS base station 204, provide precise positioning information using real-time kinematic or differential GPS techniques. Sensor data from gyro 108 is used to provide orientation information for the virtual model. Data from pressure sensors 110 provides depth information for those portions of structure 100 which are located below water level. Data from tilt meters 112 provides attitude information regarding structure 100.

At step 512, the current state of structure 100, i.e., the position, attitude and orientation of structure 100, is displayed on display 212. **Figure 6** shows an exemplary display layout. **Figure 6** is composite display showing a number of windows 602, 604, 606, 608 and 610. Window 602 is a placement orientation window showing the current heading, i.e., orientation, of structure 100. Placement orientation window 602 includes a compass rose 620 and a position arrow 622. Position arrow 622 shows the current orientation or heading of structure 100 with regard to compass rose 620. The data required to produce the heading display in placement orientation window 602 is derived from the sensor data produced by the various sensors onboard structure 100. For example, if GPS sensors 102 are located along a centerline of structure 100, a vector can be derived and compared with real world coordinates to produce the heading arrow 622. Alternatively, if a gyro compass 108 is used, the heading information can be derived directly from the gyro compass 108 output. CPU 202 executes the instructions necessary to compute the heading information for display within window 602.

Window 604 is a tilt window and provides attitude information concerning structure 100. Tilt window 604 is made up of two vertical bars 630 and 632. Within each vertical bar 630, 632 an attitude guidance information cursor 634, 636 is located. Each attitude guidance information cursor 634, 636 moves within its respective vertical bar 632, 630 in response to attitude information signals from sensors located on structure 100. The attitude information signals may be derived from tilt meters 112 and/or GPS sensors 102. CPU 202 executes the

instructions necessary to convert these signals to attitude information for display within window 604. The attitude information cursors 634, 636 provide a visual reference indicating the degree of pitch or roll currently being experienced by structure 100.

Tilt window 604 is supplemented by tilt text window 606. Tilt text window 606 provides a textual, rather than graphical, representation of the current pitch and roll being experienced by structure 100. The information used to produce the pitch and roll parameters displayed in tilt text window 606 is obtained from the same sensors as were used to produce the information for tilt window 604. As shown in tilt text window 606, in addition to displaying the current pitch and roll of structure 100, the desired pitch and roll which have been previously stored can also be displayed. This provides an operator with the information necessary for maneuvering structure 100 along the pitch and roll axes during the positioning operation.

Window 608 is a plan view of the positioning operation. Shown in the plan view map of window 608 is a two-dimensional illustration 640 of structure 100. Structure illustration 640 indicates the current position of structure 100 during the positioning operation. Illustration 640 is shown in the orientation and position indicated by the data from the various sensors located onboard structure 100. Also shown in plan view window 608 is illustration 642 which indicates the desired position and orientation of structure 100 upon completion of the positioning operation. Using plan view window 608, an operator can readily determine the operations necessary to precisely position structure 100. Optionally shown within plan view window 608 are compass illustration 644 and grid layout 648. These features are shown and may be provided for operator convenience.

Orientation text window 610 indicates the current and desired heading of structure 100. The current heading information is derived from the sensor data just as the orientation information for window 602 was derived. The required heading information is derived from pre-programmed parameters, just as the desired pitch and roll indications were obtained.

Returning to **Figure 5**, at step 514, the structure 100 is positioned according to the information provided by the display readouts. Those skilled in the art will appreciate that the positioning operation can be performed manually, or remotely using control signals generated by CPU 202 and relayed to structure via radio 210. In such an automatic positioning embodiment, structure 100 would also contain auto pilot controls (not shown) to allow for the precise positioning of structure 100 via remote control.

At step 516 a determination is made as to whether the structure 100 has been located in the proper position, orientation and attitude. If not, the process repeats the above steps 508 to 514 until the desired position, orientation and attitude is achieved. Once the structure 100 has been positioned properly, process 500 quits at step 518.

In an alternative embodiment, after structure 100 has been positioned properly, CPU 202 collects a user defined set of data. This data may include a relatively long record of sensor information, e.g., on the order of 10 min., from the sensors onboard structure 100. The data is collected in the manner described above and stored in memory 208 or a similar storage device. The data is averaged to eliminate spurious readings (e.g., caused by noise in radio link 220) and mean values and standard deviations are computed. The result of this data collection is a virtual model that accurately reflects the "as built" status of structure 100. This information can be used to generate an "as built" report, which is a summary of the best estimate of the final position of structure 100 for an engineering report.

Thus, a method and apparatus for the precise positioning of large structures has been described. In the foregoing specification, the present invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes maybe made thereto without departing from the broader and spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. A method of positioning a three-dimensional structure comprising the steps of:

establishing a virtual model, the virtual model including a three-dimensional digital representation of the structure, the virtual model being stored in a memory;

positioning remote sensors in selected positions on the structure, the remote sensors configured to provide real-time location, attitude and orientation information regarding the structure;

associating digital representations of the positions of the remote sensors with the virtual model in a data structure in the memory;

monitoring the real-time location, attitude and orientation information provided by the remote sensors;

modifying the location, attitude and orientation of the virtual model with respect to a predefined coordinate system so as to generate a real-time virtual model which corresponds to a current location, attitude and orientation of the structure;

displaying the real-time virtual model to a user as a graphical and textual representation of the current location, attitude and orientation of the structure and simultaneously displaying a graphical and textual representation of a desired location, attitude and orientation of the structure; and

adjusting the current location, attitude and orientation of the structure so as to align the current location, attitude and orientation of the structure to the desired location, attitude and orientation of the structure.

2. The method of claim 1 wherein the remote sensors include one or more GPS sensors, and wherein the step of positioning comprises the step of:

locating the GPS sensors on the structure such that one or more antennas associated with each of the one or more GPS sensors are located at strategic points on the structure so as to provide sufficient real-time position information to allow a determination of the location, attitude and orientation of the structure.

3. The method of claim 2 wherein the remote sensors further include one or more tilt meters, and wherein the step of positioning further comprises the step of:

locating the one or more tilt meters on the structure such that the tilt meters are oriented along the major axes of the structure so as to provide pitch and roll information concerning the structure during a positioning operation.

4. The method of claim 3 wherein the remote sensors further include one or more pressure sensors, and wherein the step of positioning further comprises the step of:

locating the one or more pressure sensors on the structure such that the pressure sensors are located on portions of the structure to be submerged so as to provide depth information regarding the submerged portions of the structure.

5. The method of claim 4 wherein the remote sensors further include a gyro compass, and wherein the step of positioning further comprises the step of:

locating the gyro compass on the structure such that the gyro compass is aligned with a major axis of the structure so as to provide orientation information regarding the structure.

6. The method of claim 1 wherein the remote sensors include a GPS sensor and a tilt meter, and wherein the step of positioning comprises the steps of:

locating the GPS sensor on the structure such that one or more antennas of the GPS sensor are located at strategic points on the structure so as to provide sufficient real-time position information to allow a determination of the location of the structure; and

locating the one or more tilt meters on the structure such that the tilt meters are oriented so as to provide orientation information regarding the structure.

7. The method of claim 1 wherein the remote sensors are coupled to a communication device on the structure and wherein the step of monitoring comprises the step of:

providing the real-time location, attitude and orientation information regarding the structure produced by the remote sensors to the communication device;

modulating a communication signal with the real-time location, attitude and orientation information in the communication device and transmitting the communication signal over a communication link to a base station;

receiving the communication signal at the base station and demodulating the communication signal to extract the real-time location, attitude and orientation information; and

processing the real-time location, attitude and orientation at the base station to produce update information for the virtual model.

8. The method of claim 7 wherein the step of modifying comprises the step of:

updating the virtual model using the update information so that the location, attitude and orientation of the virtual model with respect to the predefined coordinate system corresponds with the real-time location, attitude and orientation information produced by the remote sensors.

9. The method of claim 1 wherein the step of displaying comprises the steps of:

displaying the current orientation of the structure using a compass rose and pointer arrow; and

displaying the current attitude of the structure using orthogonal pitch and roll bars, each of the pitch and roll bars having associated pitch and roll cursors.

10. The method of claim 9 wherein the step of displaying further comprises the step of:

displaying a plan view of the positioning operation, the plan view showing a two-dimensional representation of the structure, the structure being represented in its current location, attitude and orientation, the plan view further showing the desired location, attitude and orientation of the structure.

11. A precise positioning apparatus comprising:

a system bus;

a GPS receiver configured to communicate with the system bus, the GPS receiver generating position information regarding the position of a structure associated with the GPS receiver;

a memory configured to communicate with the system bus;

a display configured to communicate with the system bus;

a microprocessor configured to communicate with the system bus, the microprocessor configured to receive the position information from the GPS receiver and configured to generate display information based on the position information, the display information comprising guidance and orientation information, the microprocessor configured to transmit the display information to the display,

wherein the display information is displayed on the display such that a user is provided with a visual graphical representation of the present position, orientation and attitude of the structure and the desired position, orientation and attitude of the structure.

12. A precise positioning apparatus as in claim 11 further comprising a communication system, the communication system coupled to the GPS receiver and to the system bus, the communication system providing a link for communicating information from the GPS receiver to the microprocessor.

13. A precise positioning system as in claim 12 wherein the communication system comprises a two-way radio communication system.

14. A communication system as in claim 12 wherein the communication system comprises an optical communication system.

15. A precise positioning system as in claim 12 further comprising an orientation sensor, the orientation sensor generating orientation information regarding the orientation of the structure, the orientation sensor coupled to the communication system, wherein the communication system further providing a link for communicating orientation information from the orientation sensor to the microprocessor.

16. A precise positioning system as in claim 15 wherein the orientation sensor comprises a gyro compass.

17. A precise positioning system as in claim 12 further comprising an attitude sensor, the attitude sensor generating pitch information regarding the structure, the attitude sensor coupled to the communication system, wherein the communication system further providing a link for communicating the pitch information from the orientation sensor to the microprocessor.

18. A precise positioning system as in claim 17 wherein the attitude sensor further generating roll information regarding the structure, and wherein the communication system further providing a link for communicating the roll information to the microprocessor.

19. A precise positioning system as in claim 18 wherein the attitude sensor comprises a tilt meter.

20. A precise positioning system as in claim 12 further comprising a pressure sensor, the pressure sensor generating depth information regarding the structure, the pressure sensor coupled to the communication system, wherein the communication system further providing a link for communicating the depth information from the pressure sensor to the microprocessor.

21. A method of generating an as built report regarding a structure, the method comprising the steps of:

positioning remote sensors in selected positions on the structure, the remote sensors configured to provide real-time location, attitude and orientation information regarding the structure;

monitoring the real-time location, attitude and orientation information provided by the remote sensors and using the information to create a virtual representation of the structure, the virtual representation being stored in a memory of a computer system;

terminating the monitoring of the information and generating a report regarding the location, attitude and orientation of the structure using the virtual representation.

ABSTRACT

A three dimensional structure is precisely positioned at a desired location. A virtual model of the structure of interest is created and stored in a computer memory. Some time later, remote sensors are placed in selected positions on the structure of interest. The sensors are configured so as to provide real time location, attitude and orientation information regarding the structure and may consist of GPS remote units, tilt meters, gyro compasses, and pressure sensors. The position of each the remote sensors on the actual structure is also recorded in the computer memory so that the virtual model accurately reflects the configuration of the structure. As the structure is being positioned, the real-time location, attitude and orientation information produced by the remote sensors is monitored at a base station and used to update the virtual model. In this way, the virtual model accurately reflects the current location, attitude and orientation of the structure. The information so obtained can be displayed to a user as a graphical and textual representation of the current state of the structure. The desired location, attitude and orientation of the structure is also displayed, thereby allowing a user to adjust the current location, attitude and orientation of the structure so as to align the current position of the structure to desired position. As built reports are produced upon completion of the positioning operation.

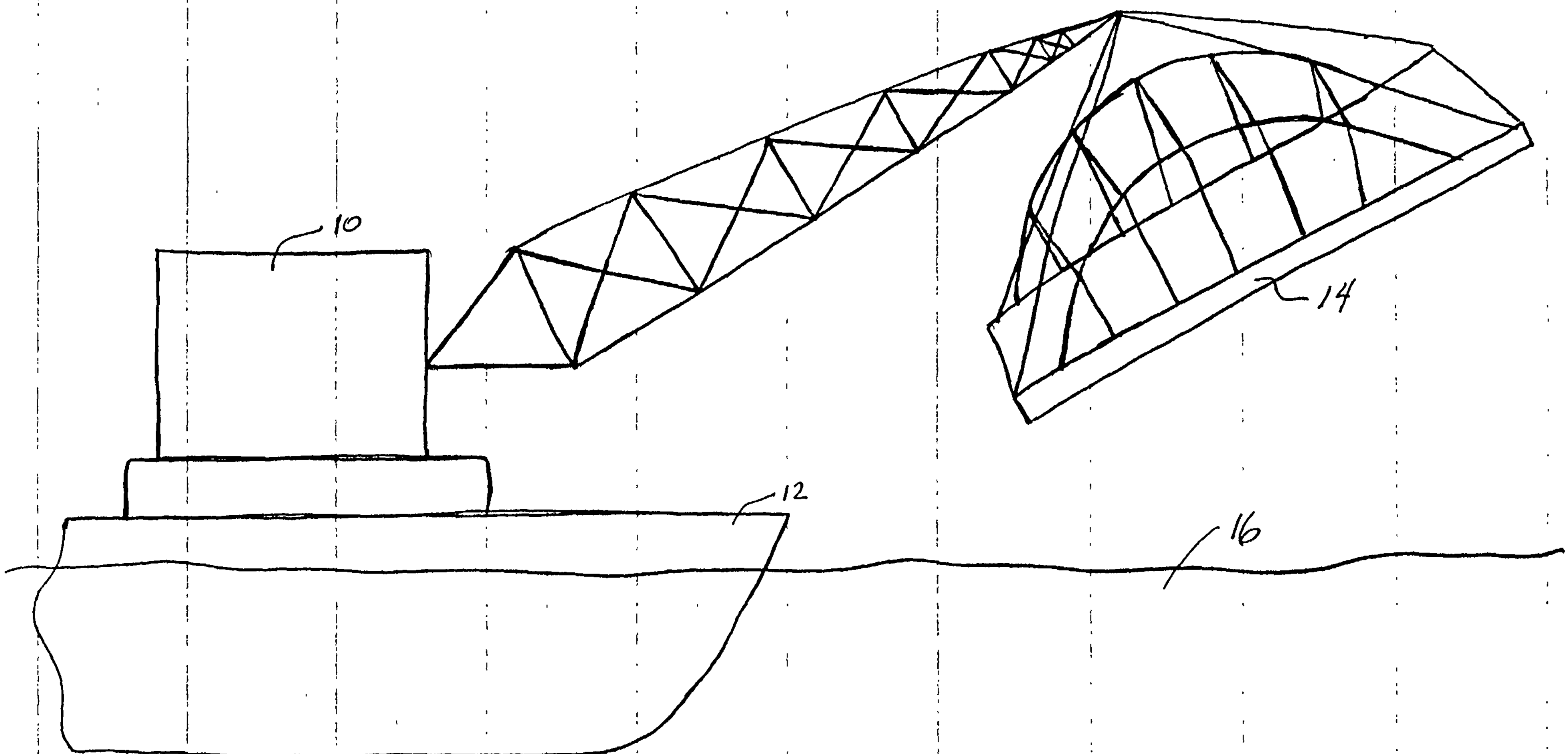
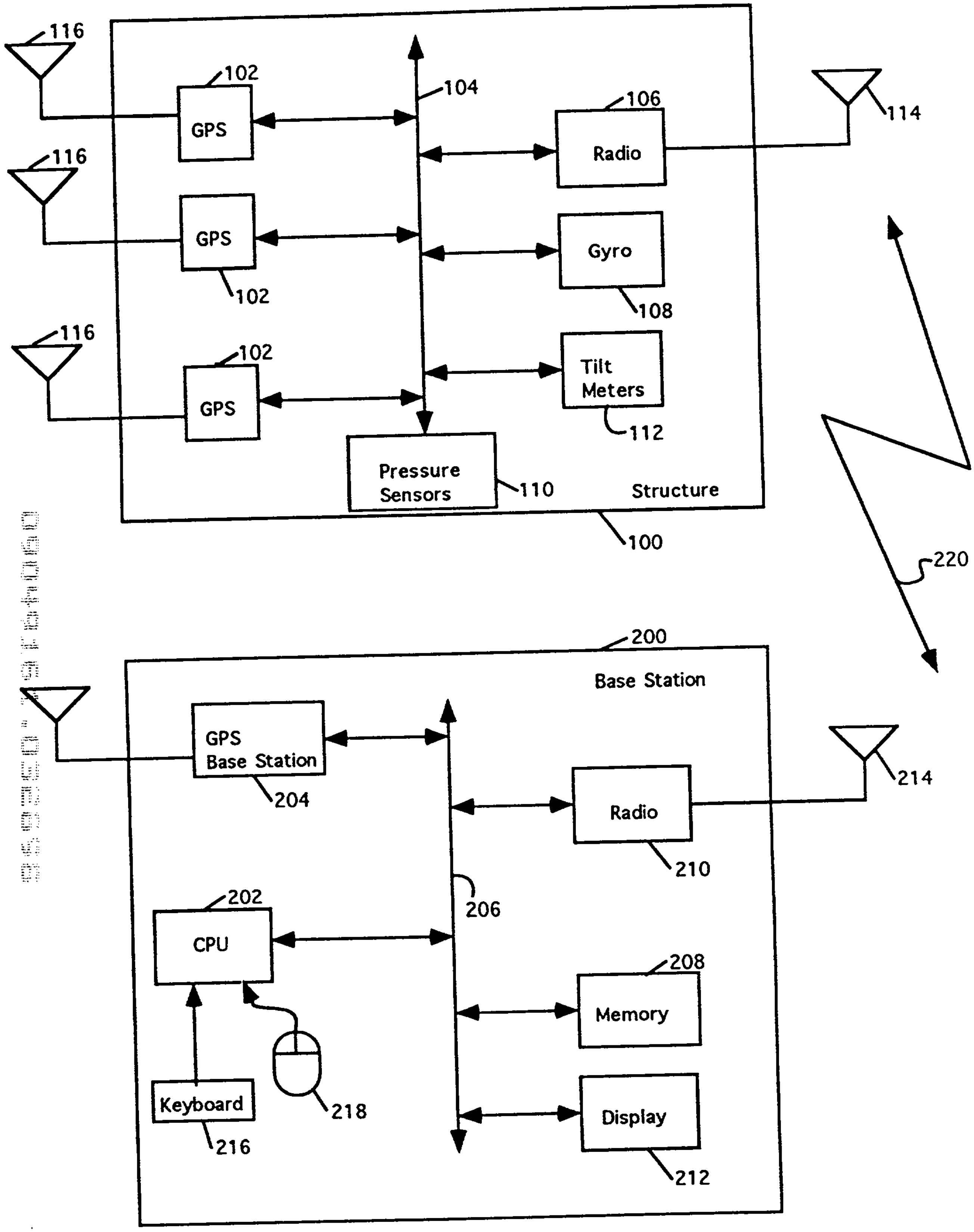


FIGURE 1


116
102
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106
114
GPS
Radio
116
GPS
Gyro
102
108
116
102
Tilt Meters
GPS
112
Pressure Sensors
110
Structure
100
220
200
Base Station
GPS Base Station
204
214
Radio
210
202
206
CPU
208
Memory
218
Keyboard
Display
216
212

FIGURE 2

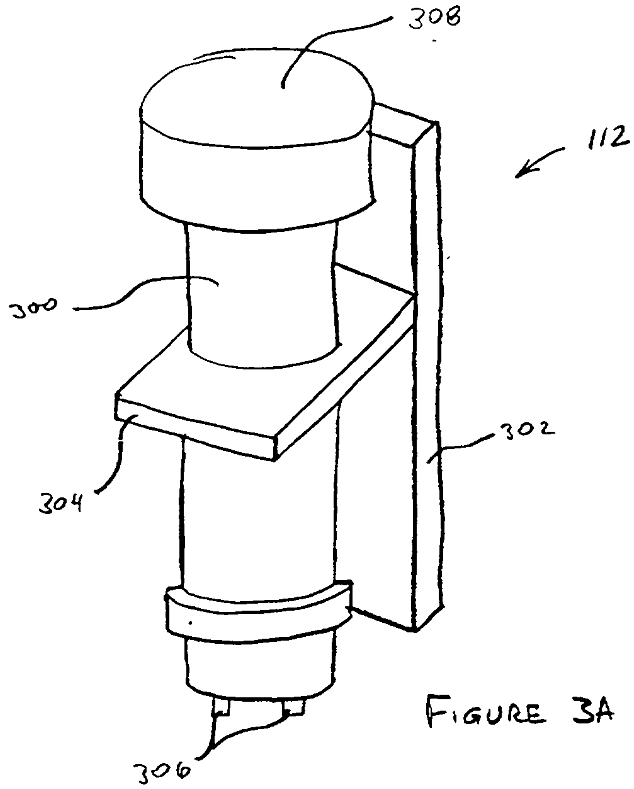


FIGURE 3A

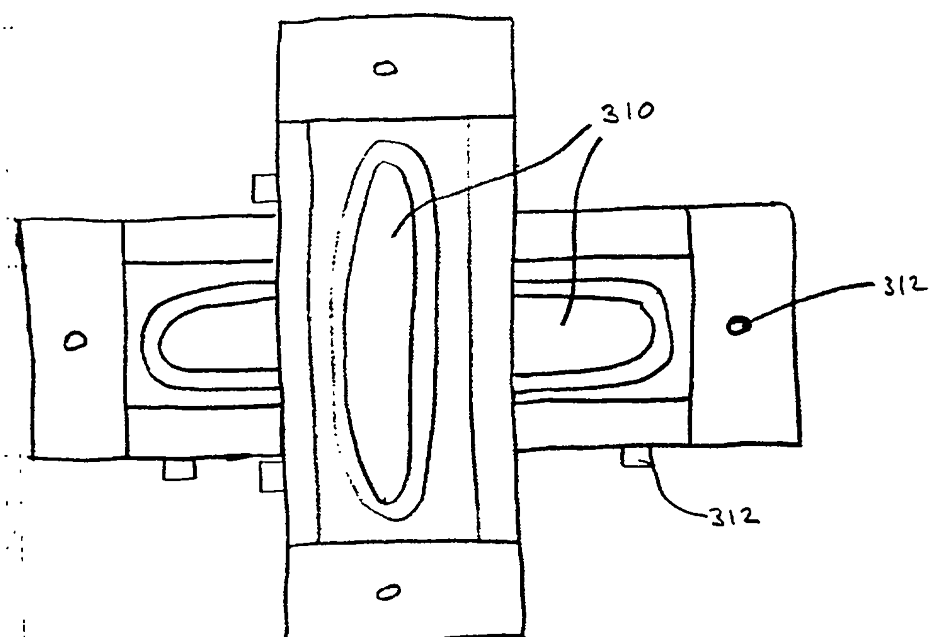


FIGURE 3B

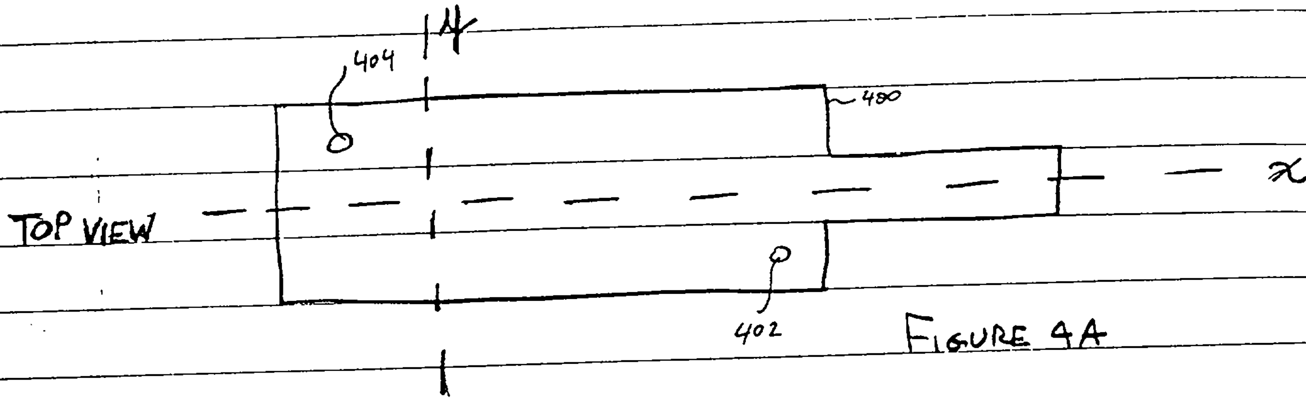


FIGURE 4A

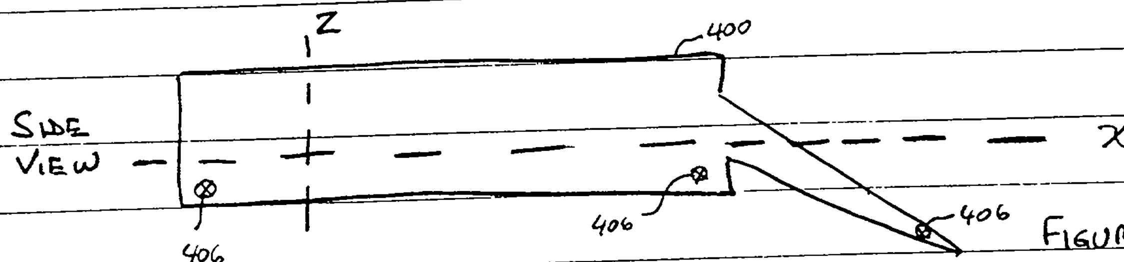


FIGURE 4B

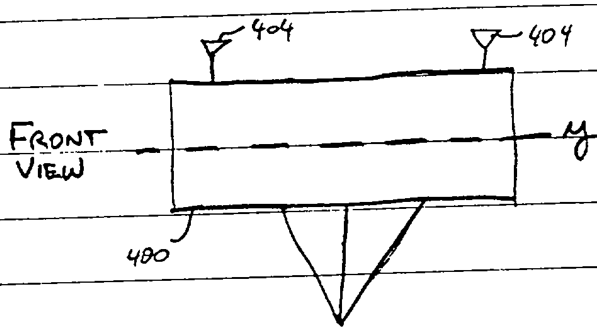


FIGURE 4C

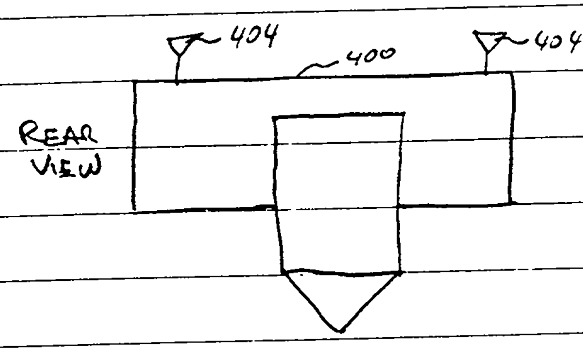


FIGURE 4D

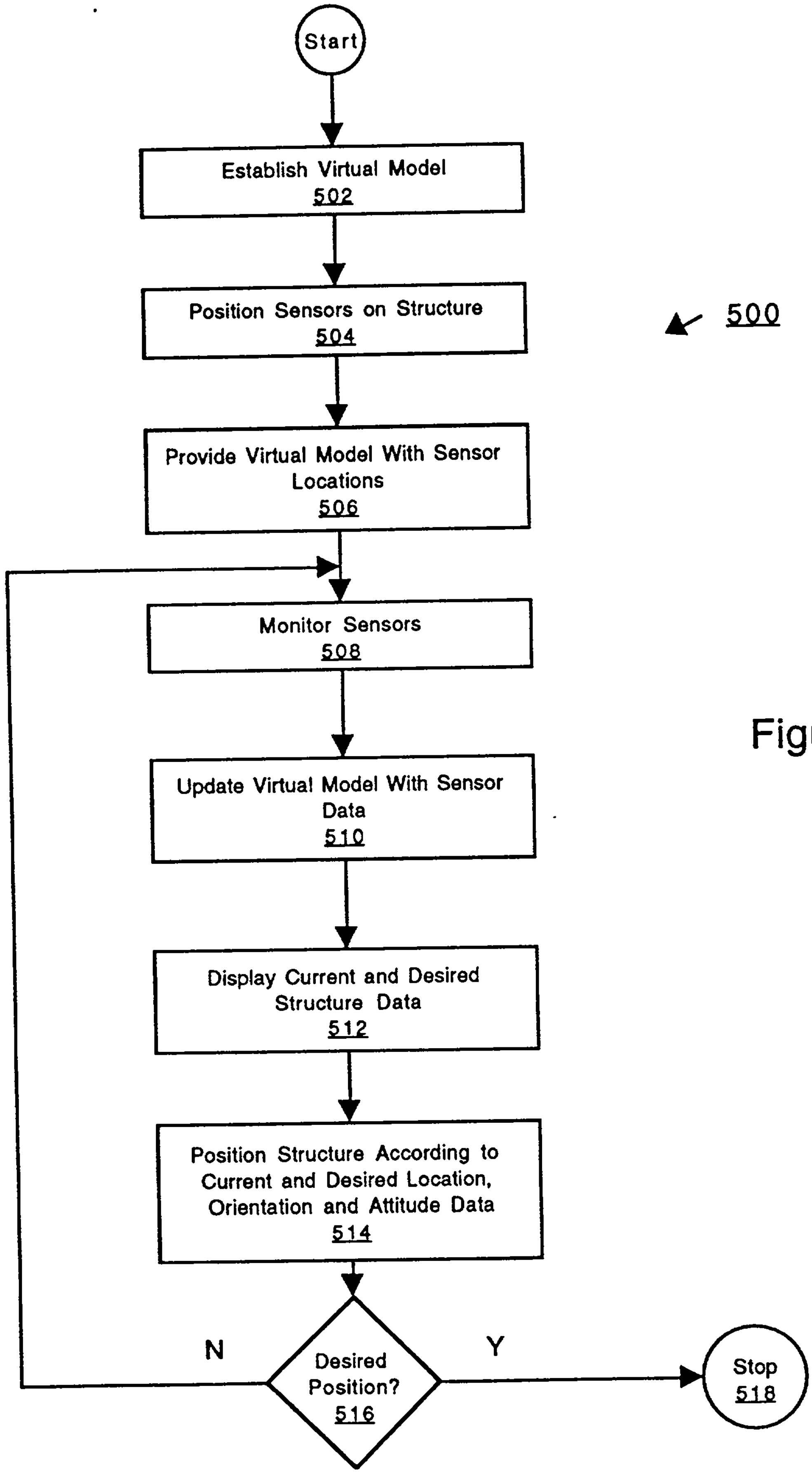
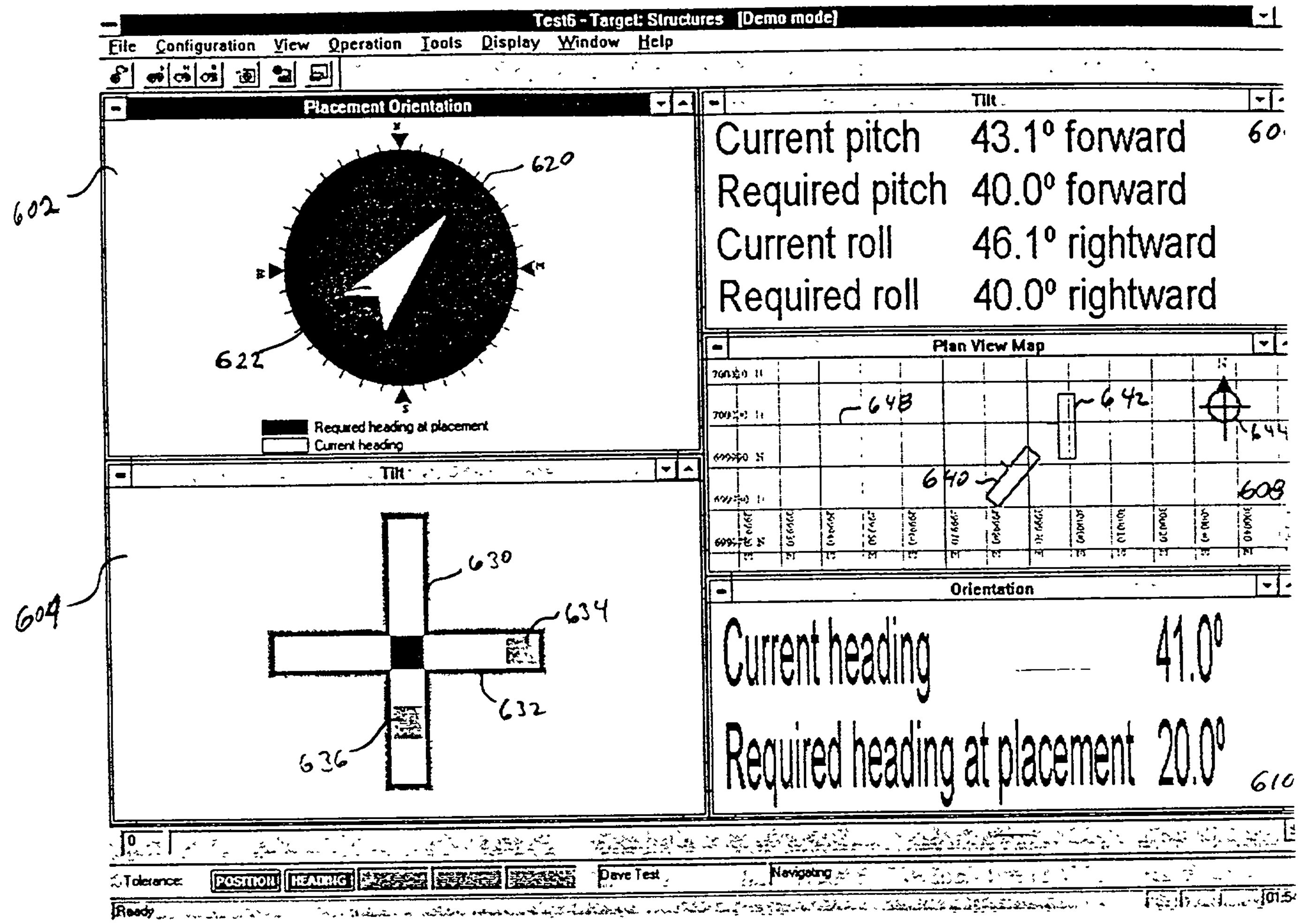

Start
Establish Virtual Model
502
Position Sensors on Structure
504
500
Provide Virtual Model With Sensor Locations
506
Monitor Sensors
508
Update Virtual Model With Sensor Data
510
Display Current and Desired Structure Data
512
Position Structure According to Current and Desired Location, Orientation and Attitude Data
514
N
Desired Position?
516
Y
Stop
518

Figure 5



Test6 - Target: Structures [Demo mode]
File Configuration View Operation Tools Display Window Help
Placement Orientation
Tilt
Current pitch 43.1° forward
Required pitch 40.0° forward
Current roll 46.1° rightward
Required roll 40.0° rightward
Required heading at placement
Current heading
Tilt
Plan View Map
Orientation
Current heading 41.0°
Required heading at placement 20.0°
Tolerance: POSITION HEADING
Dave Test
Navigating
Ready
602
604
620
622
630
632
634
636
640
642
644
648
608

FIGURE 6

Attorney's Docket No.: 02240.P015 PATENT

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below, next to my name.

I believe I am the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

"METHOD AND APPARATUS FOR PRECISE POSITIONING OF LARGE STRUCTURES"

the specification of which

XX is attached hereto.
____ was filed on ________________ as
United States Application Number __________
or PCT International Application Number __________
and was amended on ____________.
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above.

I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d), of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Claimed	
(Number)	(Country)	(Day/Month/Year Filed)	Yes	No
(Number)	(Country)	(Day/Month/Year Filed)	Yes	No
(Number)	(Country)	(Day/Month/Year Filed)	Yes	No

I hereby claim the benefit under title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below

(Application Number)	Filing Date
(Application Number)	Filing Date

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Number)	Filing Date	(Status -- patented, pending, abandoned)
(Application Number)	Filing Date	(Status -- patented, pending, abandoned)

I hereby appoint Aloysius T. C. AuYeung, Reg. No. 35,432; William Thomas Babbitt, Reg. No. 39,591; Kent D. Baker, Reg. No. 38,822; Jordan Michael Becker, Reg. No. 39,602; Bradley J. Bereznak, Reg. No. 33,474; Michael A. Bernadicou, Reg. No. 35,934; Roger W. Blakely, Jr., Reg. No. 25,831; Gregory D. Caldwell, Reg. No. 39,926; Kent M. Chen, Reg. No. 39,630; Lawrence M. Cho, Reg. No. 39,942; Thomas M. Coester, Reg. No. P39,637; Roland B. Cortes, Reg. No. 39,152; William Donald Davis, Reg. No. 38,428; Daniel M. De Vos, Reg. No. 37,813; Karen L. Feisthamel, Reg. No. 40,264; Scot A. Griffin, Reg. No. 38,167; David R. Halvorson, Reg. No. 33,395; Brian Don Hickman, Reg. No. 35,894; Eric Ho, Reg. No. P39,711; George W Hoover II, Reg. No. 32,992; Eric S. Hyman, Reg. No. 30,139; Jeffrey D. Jacobs, Reg. No. 40,029; Dag H. Johansen, Reg. No. 36,172; Stephen L. King, Reg. No. 19,180; Dolly M. Lee, Reg. No. 39,742; Daniel C. Mallery, Reg. No. 33,532; Michael J. Mallie, Reg. No. 36,591; Kimberley G. Nobles, Reg. No. 38,255; Ronald W. Reagin, Reg. No. 20,340; James H. Salter, Reg. No. 35,668; William W. Schaal, Reg. No. 39,018; James C. Scheller, Reg. No. 31,195; Maria McCormack Sobrino, Reg. No. 31,639; Stanley W. Sokoloff, Reg. No. 25,128; Allan T. Sponseller, Reg. No. 38,318; Steven R. Sponseller, Reg. No. 39,384; David R. Stevens, Reg. No. 38,626; Edwin H. Taylor, Reg. No. 25,129; Lester J. Vincent, Reg. No. 31,460; John Patrick Ward, Reg. No. 40,216; Ben J. Yorks, Reg. No. 33,609; and Norman Zafman, Reg. No. 26,250; my attorneys; and Gary B. Goates, Reg. No. 35,159; Michael Anthony DeSanctis, Reg. No. 39,957; Charles E. Shemwell, Reg. No. 40,171; Edwin A. Sloane, Reg. No. 34,728; and Judith A. Szepesi, Reg. No. 39,393; my patent agents, of BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN, with offices located at 12400 Wilshire Boulevard, 7th Floor, Los Angeles, California 90025, telephone (310) 207-3800, with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith.

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(Name of Attorney or Agent)
ZAFMAN, 12400 Wilshire Boulevard 7th Floor, Los Angeles, California 90025 and direct telephone calls to Maria McCormack Sorbino, (408) 720-8598.
(Name of Attorney or Agent)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Inventor's Signature A. Monnox Date 1st JULY 1996

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Title 37, Code of Federal Regulations, Section 1.56
Duty to Disclose Information Material to Patentability

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclosure information exists with respect to each pending claim until the claim is cancelled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is cancelled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclosure all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) Prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) The closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made or record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.